Competitive Academic Agreement Program

Application of Amorphous Metals for Plastic Pipeline Detection

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Main Objective

Evaluate the potential for using amorphous metal foil to enable the belowground detection of plastic pipelines.

Project Team

- Principle Investigator: Christopher Martin, Ph.D., University of North Dakota-Energy & Environmental Research Center.
- Student Researcher: Daniel Sprengelmeyer, UND Petroleum Engineering.
- Industrial Partner: Eric Theisen, Ph.D., Metglas Inc.

EERC

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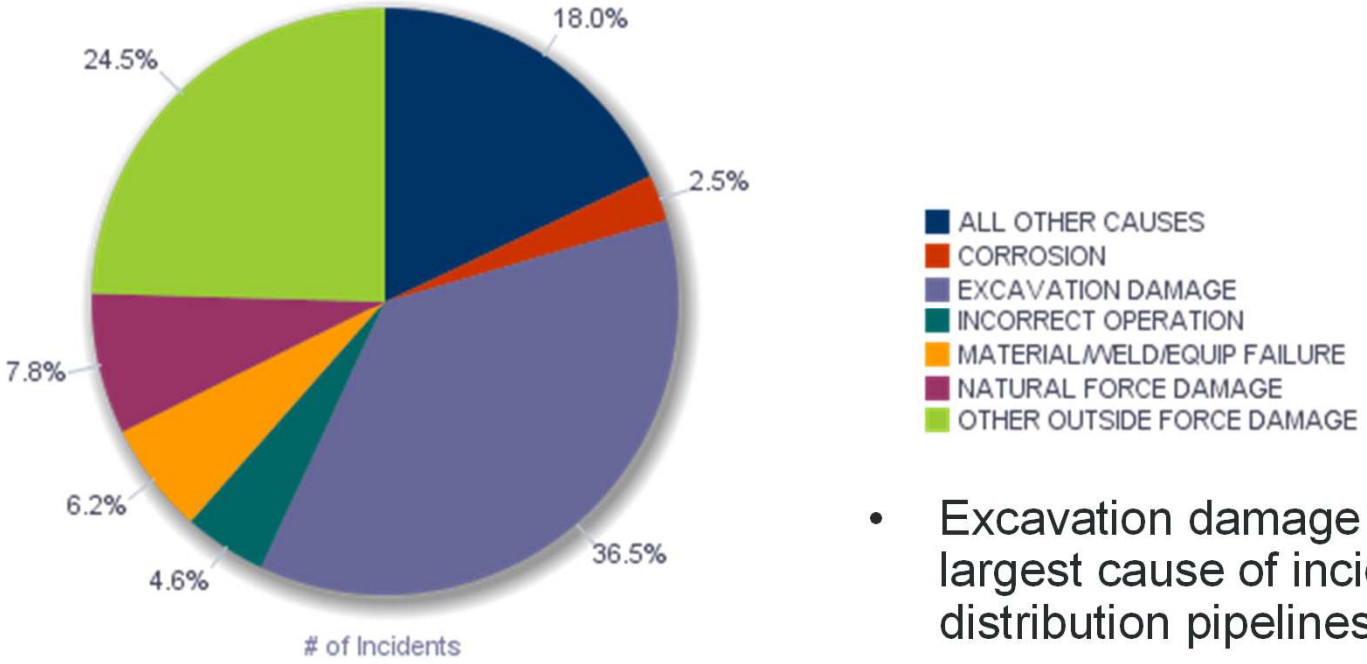
Outline

- Background and Introductory Material
  - Amorphous Metals
  - Magnetic Locating
- Field Distortion Measurements
- Application Concept
- Summary

Natural Gas Distribution Line Damage

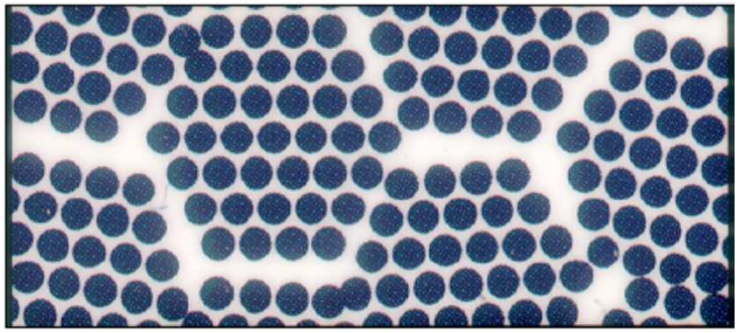


All reported incident causes for natural gas distribution systems (1996-2015). Source: U.S. DOT Pipeline and Hazardous Materials Safety Administration

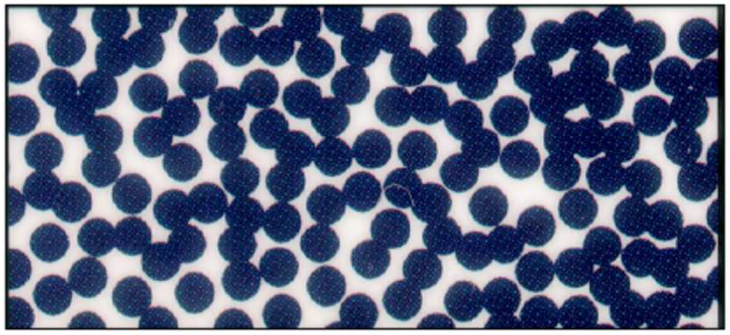
- Excavation damage ranks as the single largest cause of incidents in gas distribution pipelines.
- Over the last 20 years, excavation damage caused $219 million in reported damages and 109 fatalities.
- 69% of the nation's 2.15 million miles of distribution piping are plastic.

Amorphous Metals Introduction

Polycrystalline representation with grain boundaries.

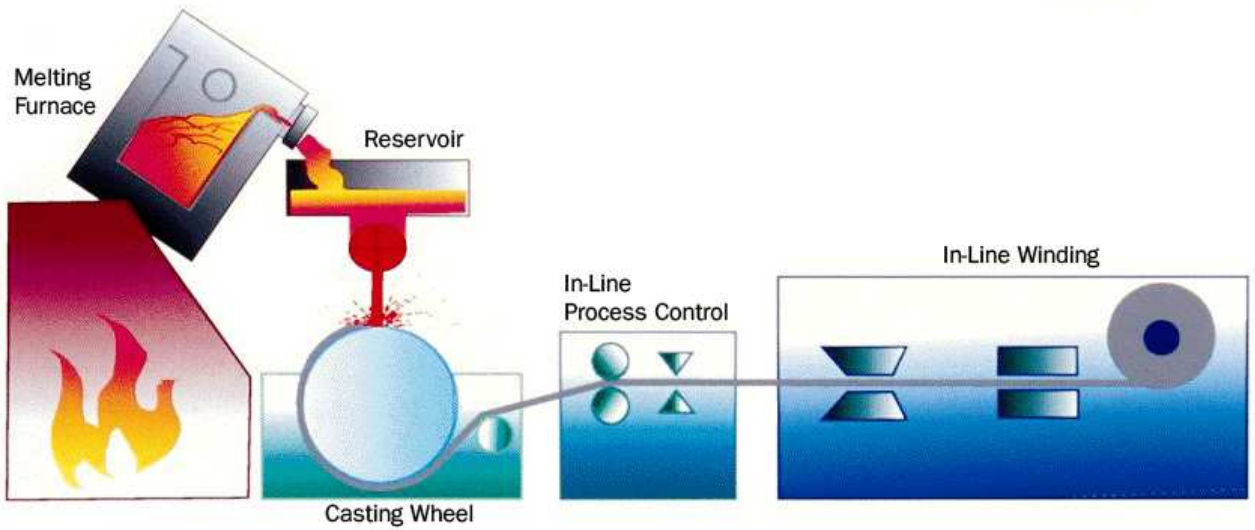


Amorphous material representation.



- Amorphous metals are a non-crystalline, glass-like state of metals and metal alloys.
- Grain boundaries within conventional crystalline metals serve as weak links for material failure, corrosion initiation.
- Two categories:
  - Bulk metallic glasses
  - Amorphous metal foil

Amorphous Ribbon Production



Metglas Inc.

- Amorphous metal foils are produced kinetically by rapid quenching from a molten state.
- Current applications include:
  - Power transformer coils
  - Anti-theft tags
  - Heating elements
  - Brazing foils

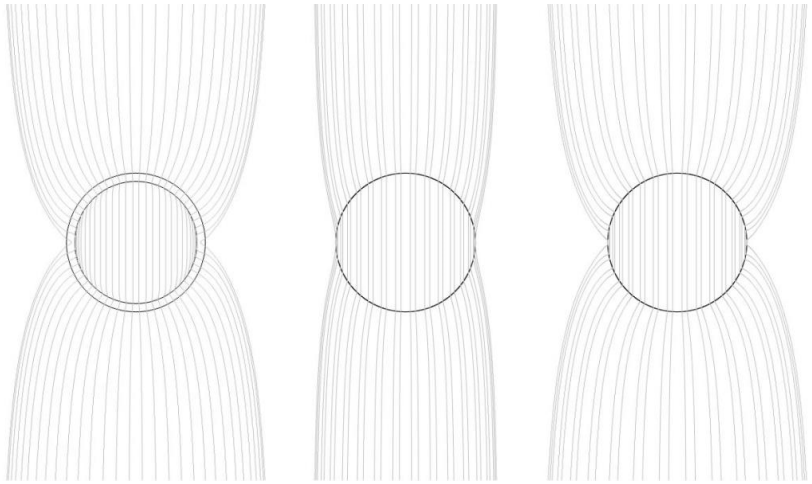
Amorphous Power Transformer Core, Metglas Inc.

Amorphous Metal Properties

Electromagnetic Property Comparison

Material	Magnetic Field Relative Permeability	Electric Field Relative Permittivity
Vacuum	1	1
Air	≈ 1	≈ 1
Water	≈ 1	81
Concrete	≈ 1	4.5
Copper	≈ 1	≈ 1
Carbon Steel	100	≈ 1
Iron	5000	≈ 1
Amorphous Metals	50,000-1,000,000	≈ 1

Magnetostatic Field Modeling



4 inch sch. 40 cast iron pipe

50 micron shell of cast iron around 4 inch pipe diameter (μ_r = 1000)

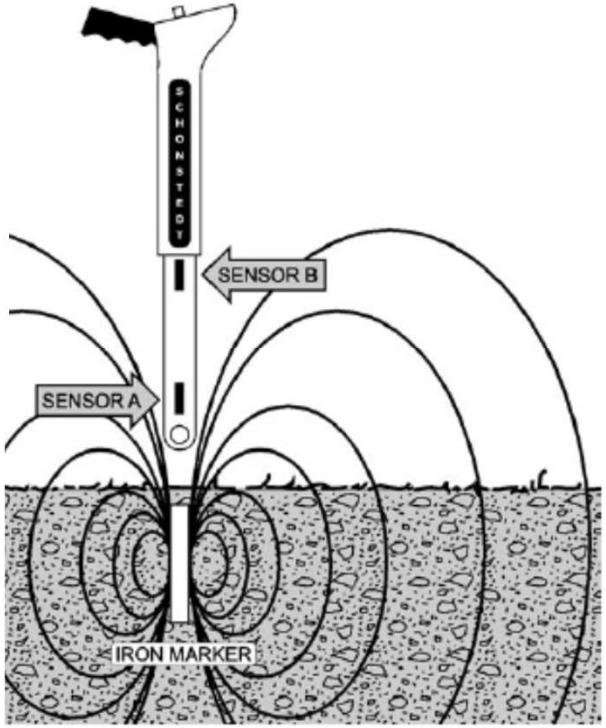
50 micron shell of Metglas around 4 inch pipe diameter (μ_r = 80,000)

Magnetic Locating

- Passive detection method that senses anomalies in Earth's magnetic field.
- Commercially-available detectors.
- Largely unaffected by soil, water, and non-ferrous conductors.
- High sensitivity instruments:
  - Earth's vertical flux density at Grand Forks is ~54,000 nT, typical differential signal range 10 to 1000 nT (0.1 to 10 mG).

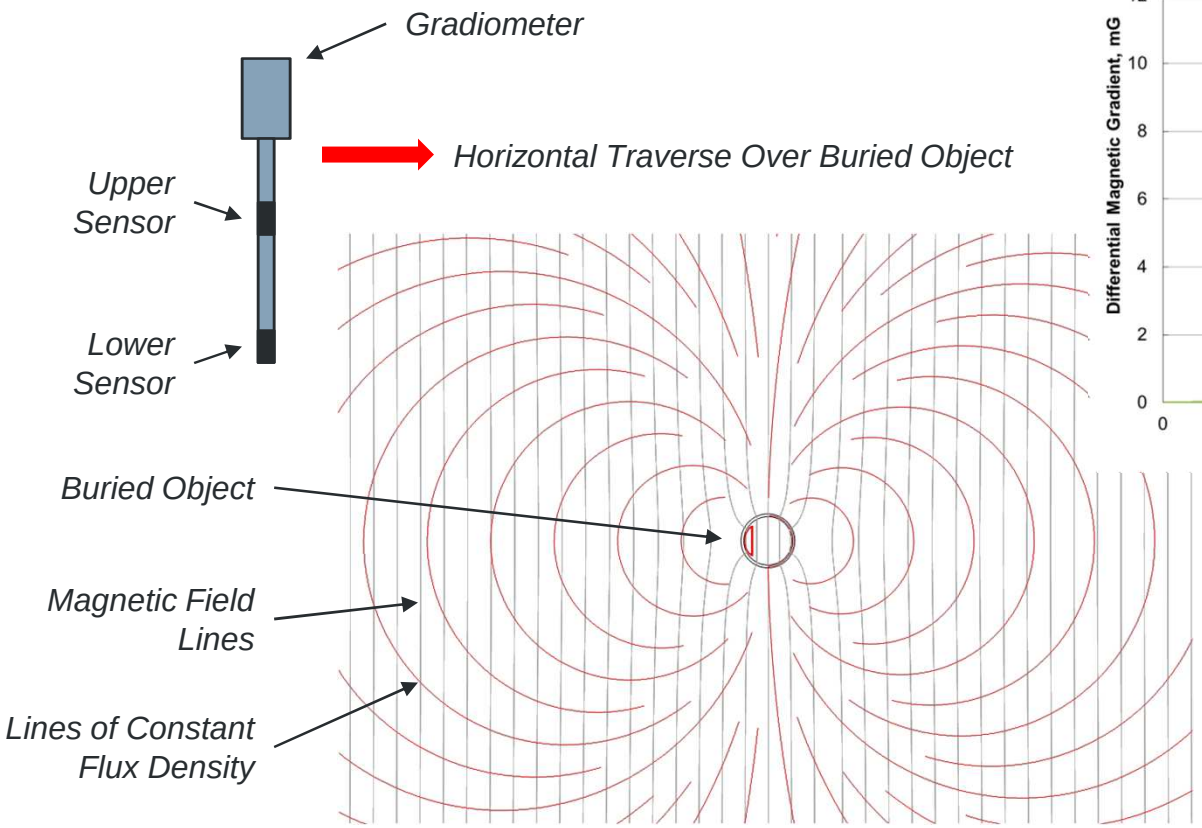
Schonstedt

CST-Berger

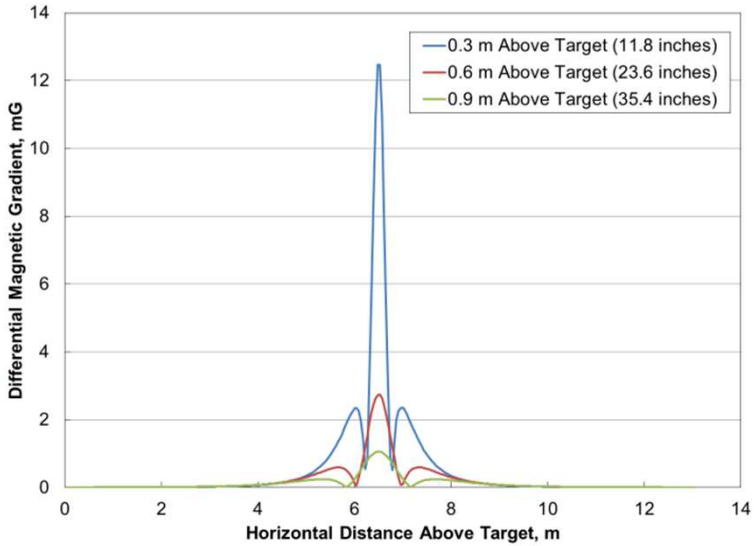


Ferromagnetic objects locally distort the Earth's magnetic field and can be detected using the differential signal from two magnetometer sensors. (Schonstedt)

Differential Magnetic Gradient



Relation between magnetic field lines (gray) and lines of constant flux density (red).



Magnetostatic modeling results for a 4 inch pipe cross section.

Field Distortion Measurements

Data Collection

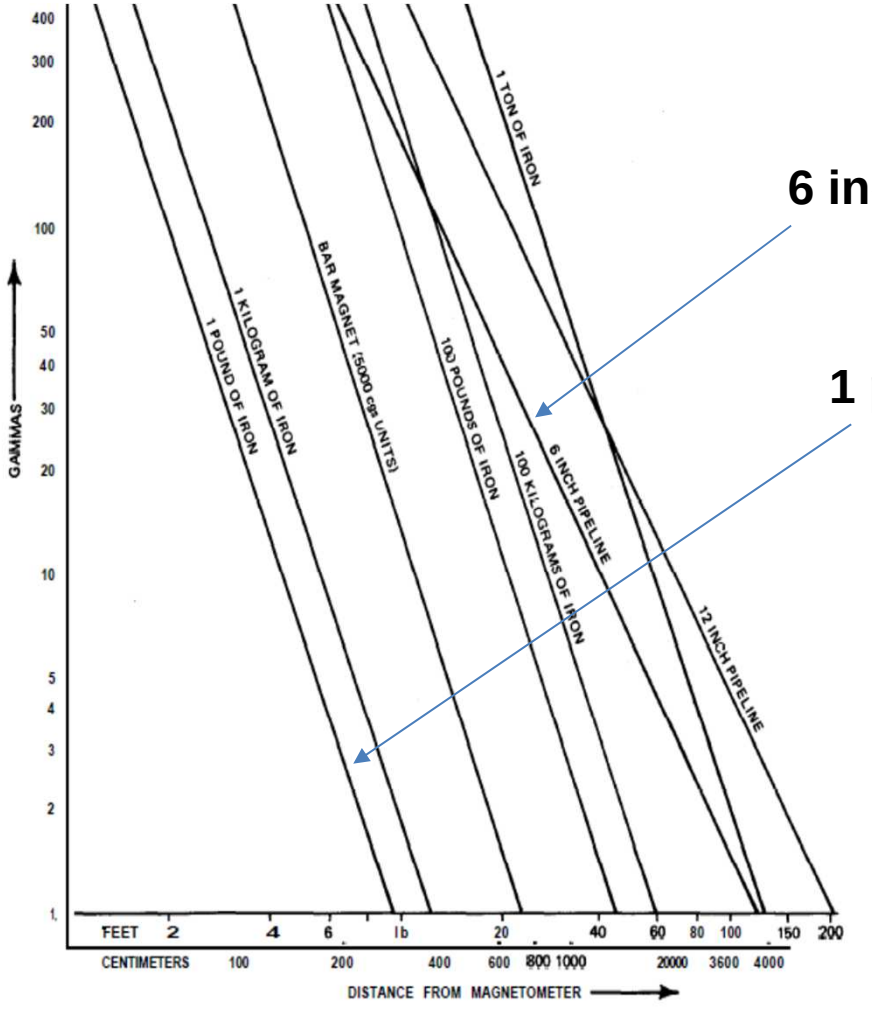
- Compass direction
- Sensing height and horizontal position
- Starting and ending background readings
- Target reading

Data Reduction

- Data corrected for background reading and polarity, then averaged.

Detectability Trends

Flux Density Gradient/Differential
Gamma = nT
100 nT = 1 mG



6 inch pipe

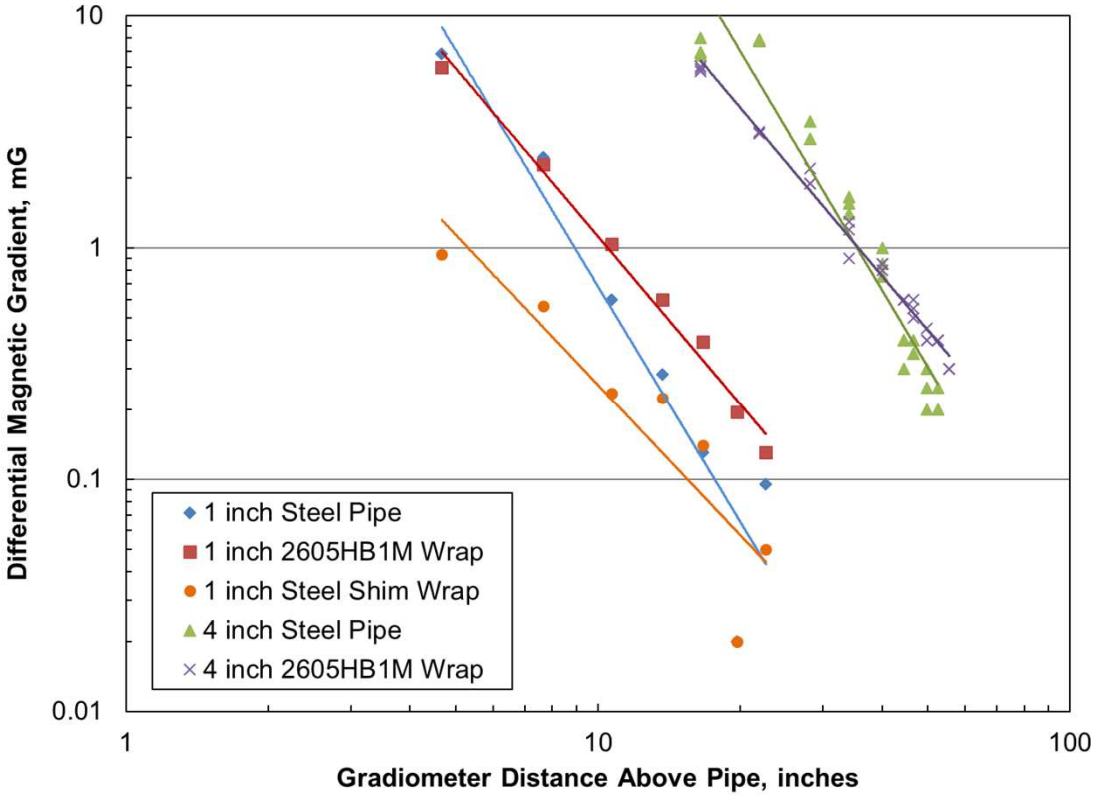
1 pound of iron

Distance/Height Above Target

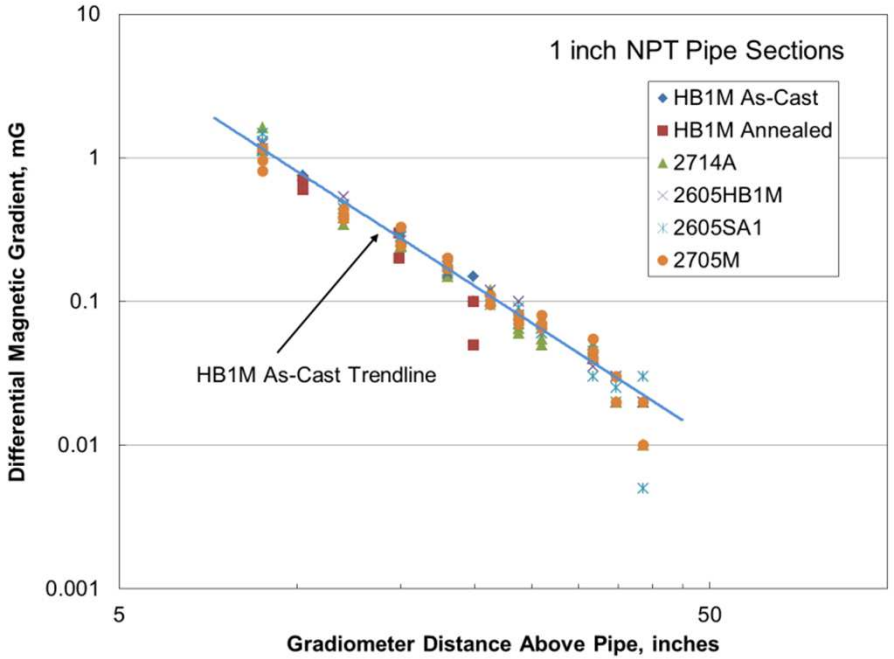
Nomogram for estimating anomalies from typical objects. Source: Breiner, S.; 1999; Applications Manual for Portable Magnetometers; Geometrics; San Jose, CA.

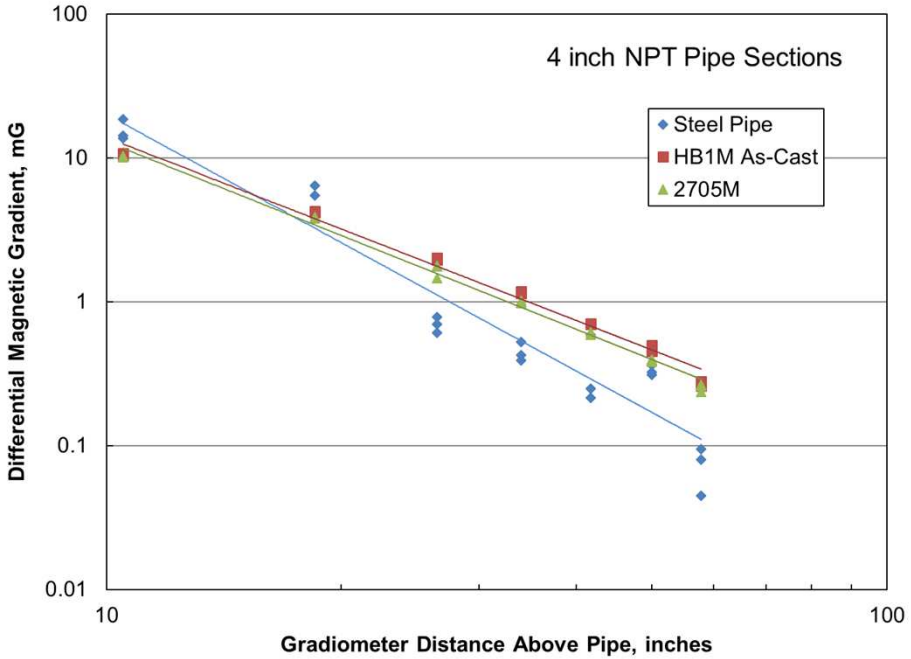
Wrapped Pipe Trends

Amorphous ribbon-wrapped PVC and steel pipes.



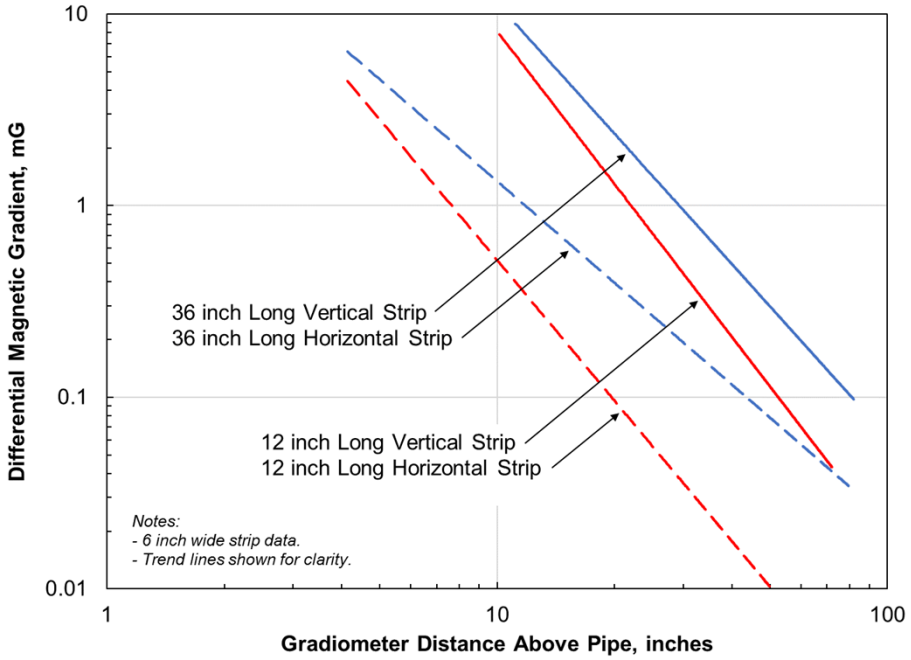
Amorphous Foil Comparison

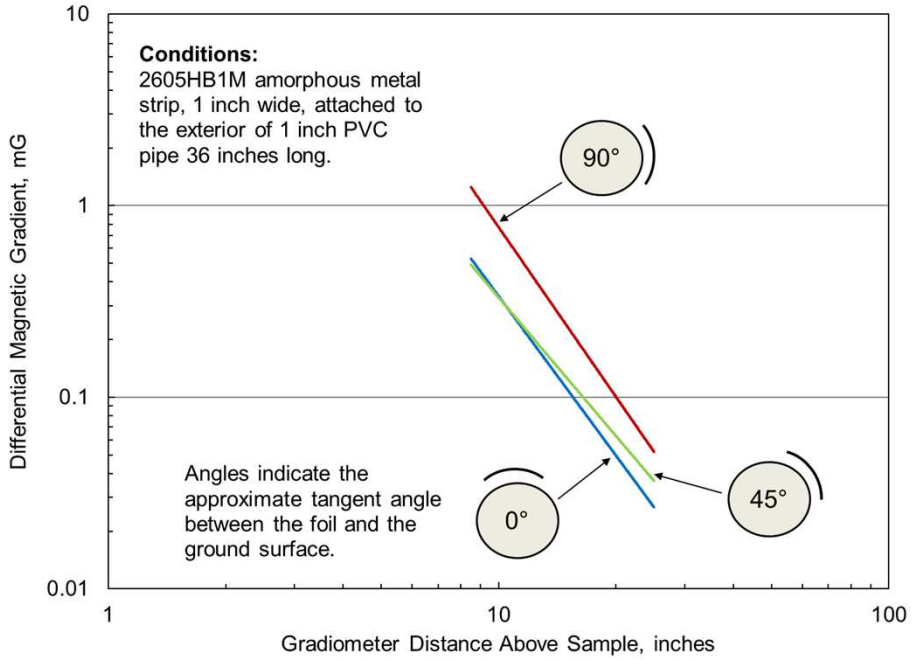


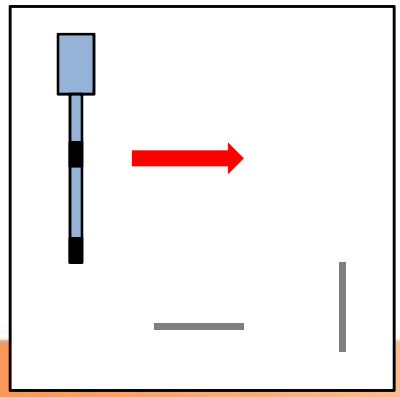


Alloy	Saturation Induction (T)	Relative Permeability	Composition
2605CO	1.15	156,400	Fe-Co-B
2605HB1M	0.958	159,900	Fe-B-Si
2605SA1	0.829	67,890	Fe-B-Si
2705M	0.754	929,300	Co-B-Si
2714A	0.602	190,000	Co-B-Si

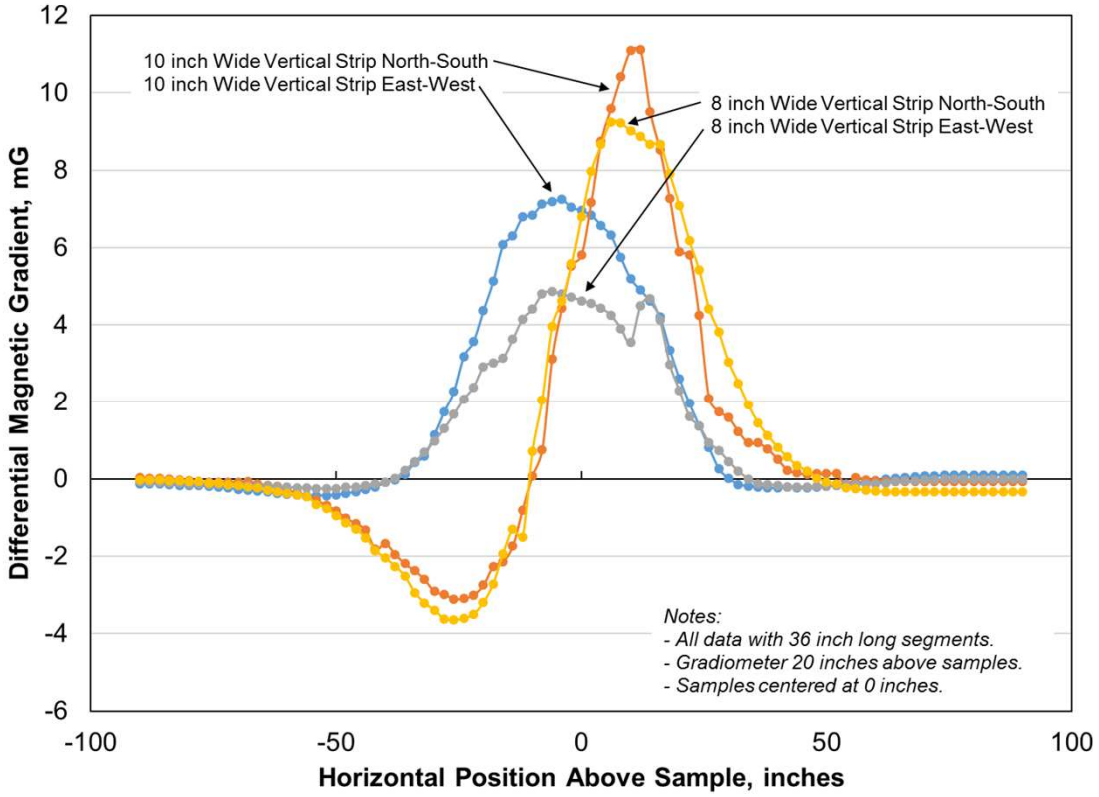
Ribbon Orientation

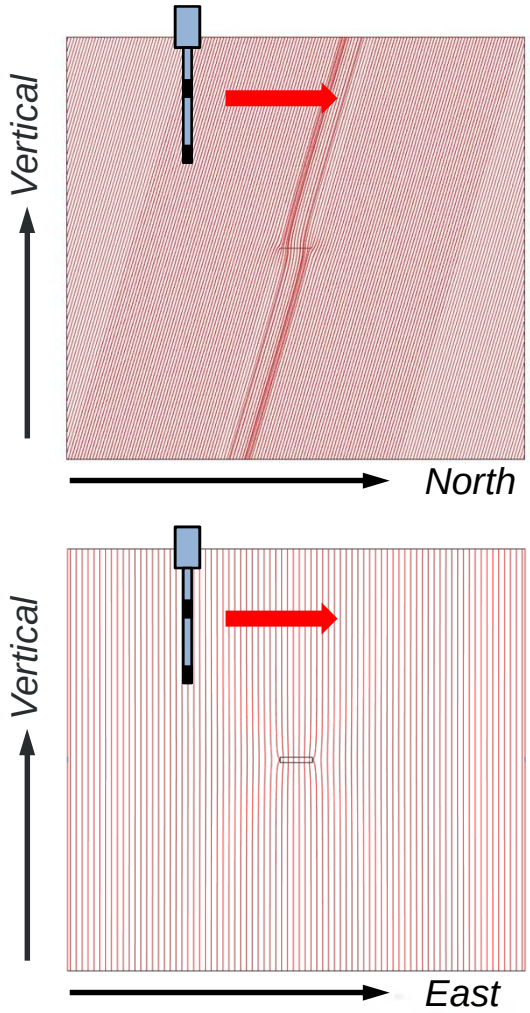






Magnetic Field Orientation





Locating Characteristics

Magnetic locating using amorphous metal ribbon:

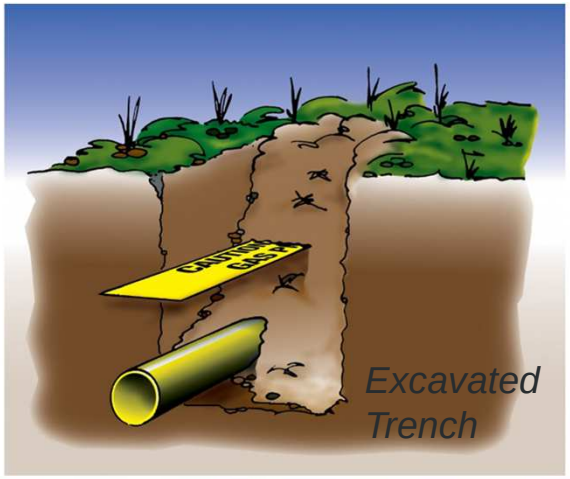
- Simple, passive
- Low material cost
- Maximum sensitivity with:
  - Vertical ribbon profile
  - Long length
  - Limited depth

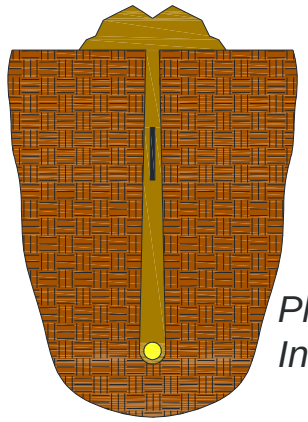
Comparison to Other Locating Techniques

Locating Approach	Amorphous Metal Advantage
Conductive Tracer Wire or Tape with Electric Field Detection	Passive detection, no conductive circuit; lower interference.
Radio Frequency Identification (RFID)	Continuous pathway rather than discrete point marking.
Ground Penetrating Radar and Other Reflected Signal Mapping	Simple, less costly locating instruments needed for uncongested routine marking.
Sonde or Beacon Locating	Pipe internal access not needed.
Magnetizable Plastic Pipe (under development)	Does not alter the composition or the properties of the pipe.

Detectable Tape Application

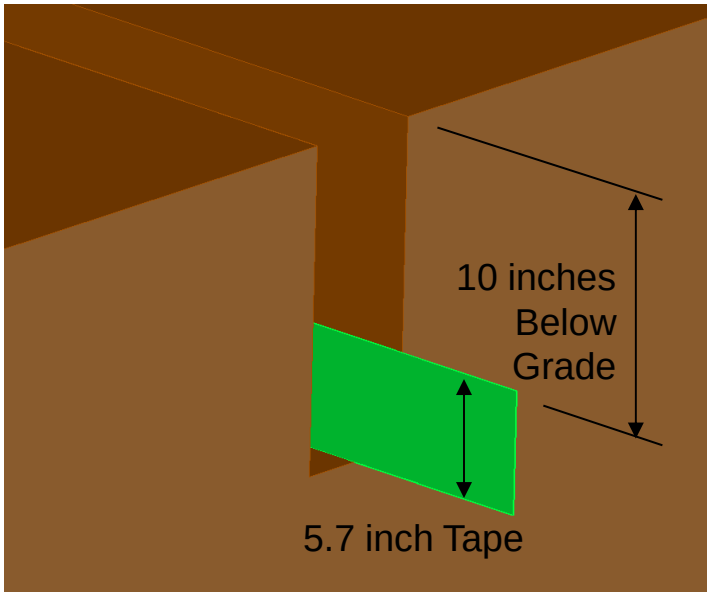
- Underground marking tapes are intended to provide a visual warning during digging.
- Aluminum versions can be detected using electric field devices.
- An amorphous-based tape would also be magnetically locatable and optimized for plowed pipe installation.



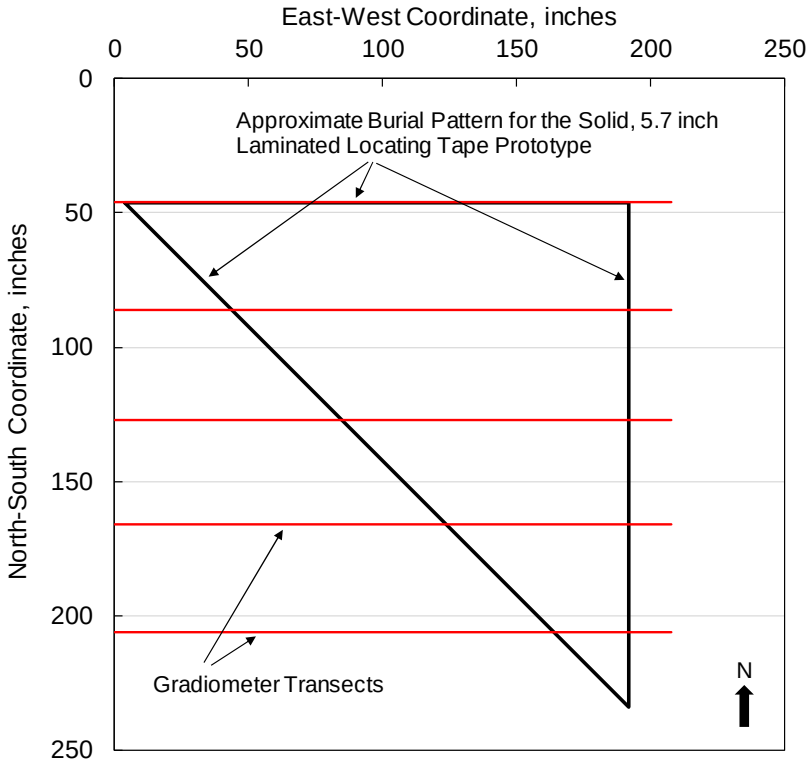


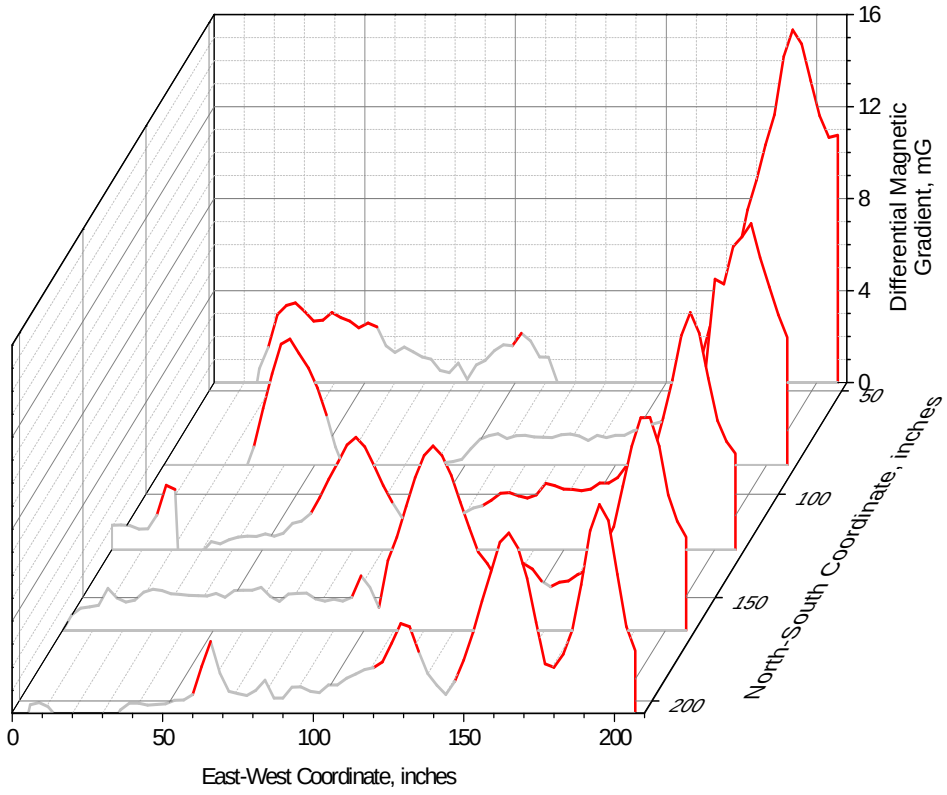
In-Ground Trial

- Metglas produced laminated detectable tape prototypes for testing.
- Segments buried at EERC to demonstrate potential use.

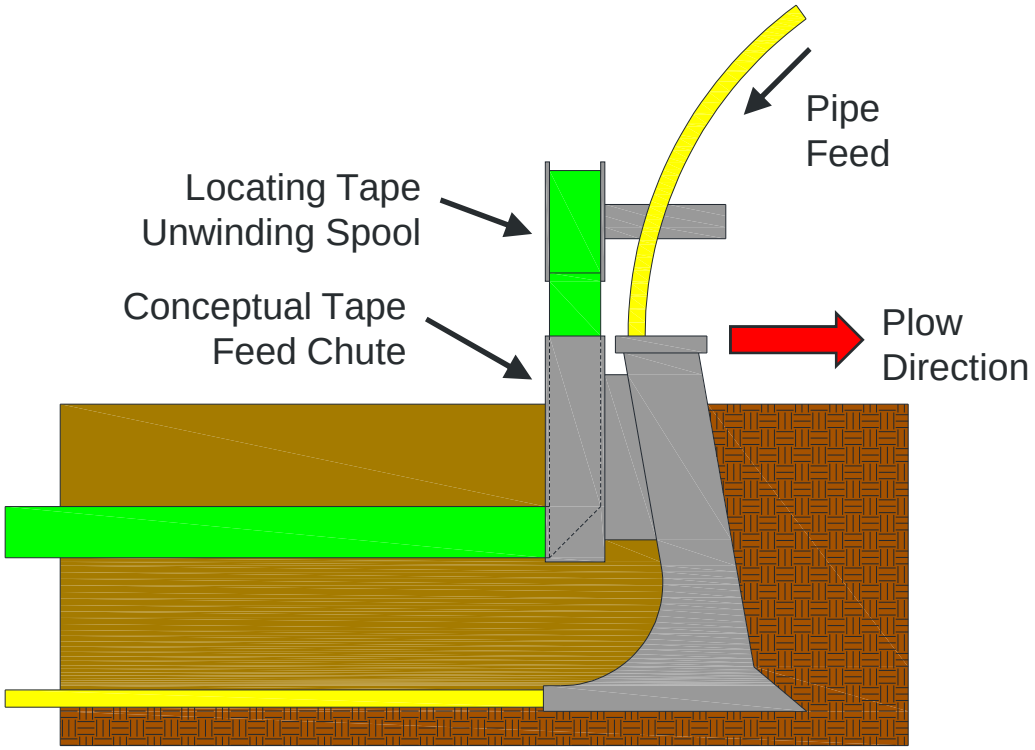


Buried Tape Sensitivity





Tape Installation Concept



Rapid installation might be possible with a modified pipe insertion plow.

Concept model: silt fence installation.

Project Summary

- Collected magnetic field distortion data for a variety of amorphous ribbon parameters: material, geometry, field orientation, etc.
- Magnetostatic modeling was conducted to extrapolate the collected data.
- Findings were synthesized to come up with a detectable tape concept employing amorphous ribbon.
- Industrial partner is investigating the market interest in amorphous foil-based locating tape.

Project Reporting

- Final Reporting and the student poster paper are available at:

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=629

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